Joint Centre for Mesoscale Meteorology, Reading, UK

The Albedo of Broken Cloud Fields: Calculations using a modified two stream radiation code

I. Dharssi
R. Kershaw

Internal Report No. 53

October 1995

Met Office Joint Centre for Mesoscale Meteorology Department of Meteorology
University of Reading PO Box 243 Reading RG6 6BB United Kingdom
Tel: +44 (0)118 931 8425 Fax: +44 (0)118 931 8791
www.metoffice.com

Designed and produced by the Met Office © Crown copyright 2001 01/0240 The Met Office logo is a registered trademark.

The Albedo of Broken Cloud Fields: Calculations using a modified two stream radiation code

Imtiaz Dharssi and Roy Kershaw

October 1995

Abstract

Cloud resolving models are a potentially useful tool for studying the cloud radiation interaction. However, such models still use plane parallel radiation transfer theory because more sophisticated methods require too much computer time. Results from Monte Carlo models show that the ratio of effective to geometric fractional cloud cover (N_e/N) is determined by the interception of direct solar radiation by the cloud sides, leakage of diffuse solar radiation through the cloud sides and cloud-cloud interactions. This note shows how the interception of direct solar radiation by the cloud sides can be included in a two stream radiation transfer code, suitable for use in cloud resolving models, which improves agreement with Monte Carlo models without requiring greater computing resources. Broken cloud fields are simulated and the ratio N_e/N calculated using the modified radiation code. At large solar zenith angles the interception of direct solar radiation by the cloud sides has the dominant effect on N_e/N and the calculated values are found to be in good quantitive agreement with the results of Kite (1987) who uses a Monte Carlo model.

1 Introduction

Numerous studies using general circulation models (GCM) show that clouds have an important effect on the Earth's radiation budget and climate. Because of the coarse spatial resolution of GCMs the cloud-radiation interaction is parameterized. This is done using plane parallel radiation transfer theory and assuming horizontally homogeneous clouds. However, both theoretical studies and observations show that the reflectivity of a finite

for use within cloud resolving models. The purpose of this note is to present a simple idea which allows some of the effects of cloud geometry to be reproduced by a modified two stream radiation transfer code, suitable for use in cloud resolving models. Use of this modified two stream code improves agreement with Monte Carlo models without requiring greater computing resources.

2 Two Stream Radiation Code

This section gives a brief description of the basic two stream equations for solar radiative transfer through a plane parallel multiple scattering (and absorbing) atmosphere. Although the material presented is standard, it is reproduced for clarity and to define the notation. Following on from this a modification to the two stream radiation code is proposed.

2.1 Standard two-stream equations

The basic two stream equations are

$$\frac{dF^+(\tau)}{d\tau} = c_1 F^+(\tau) - c_2 F^-(\tau) - \frac{c_3 F^0(\tau)}{\mu_0} \tag{2}$$

$$\frac{dF^-(\tau)}{d\tau} = c_2 F^+(\tau) - c_1 F^-(\tau) + \frac{c_4 F^0(\tau)}{\mu_0} \tag{3}$$

where τ is the optical depth, $F^+(\tau)$ and $F^-(\tau)$ are the upward and downward flux of diffuse radiation at a given τ, $F^0(\tau)$ is the direct solar flux and $\mu_0 = \cos\theta_0$ where θ_0 is the solar zenith angle. $F^0(\tau)$ is given by the simple Beer-Bouguer-Lambert law of extinction

$$F^0(\tau) = \mu_0 S_0 \exp^{-\tau/\mu_0}, \tag{4}$$

where S_0 is the local value of the solar constant.

The coefficients c_1, c_2, c_3, c_4 are given by the following equations:

$$\begin{aligned} c_1 &= D(1-\omega\alpha) \\ c_2 &= D\omega\beta \\ c_3 &= \omega\beta_0 \\ c_4 &= \omega(1-\beta_0) \end{aligned} \tag{5}$$

where D is the diffusivity factor, ω is the single scattering albedo, α and β are the fractional forward and backward scattering coefficients for diffuse radiation and β_0 is the

3 Numerical Results

The Edwards and Slingo two stream radiation code (Edwards and Slingo, 1994) is used to calculate the albedo of broken cloud fields. However, the radiation code is modified so that the calculation of the direct solar flux does not assume a plane-parallel atmosphere *ie* (8) is used instead of (4). From the calculated albedo the effective fractional cloud cover (N_e) of the broken cloud field is derived where N_e is defined as the fraction of a plane-parallel cloud layer required to give the same albedo as a broken cloud layer with the same optical properties.

Two-dimensional broken cloud fields are simulated as periodic arrays of rectangular clouds with homogeneous optical properties. Although these simulated cloud fields are not very realistic the intention is to compare our results with those from a Monte Carlo model (Kite, 1987) where a similar simplified form for broken cloud fields is used. The cloud optical properties are chosen to be similar to those used by Kite (1987). The clouds have a vertical depth of $2\,km$ with a vertical optical depth $\tau = 32$, an asymmetry factor $g = 0.85$ and a single scattering albedo $\omega = 1$ *ie* there is no absorption by cloud droplets. The cloud fields are represented on a grid with 40 levels with a vertical grid spacing of $50\,m$ and a horizontal spacing of $100\,m$. Because of this high spatial resolution the model can resolve the direct solar beam exiting one cloud and re-entering the next. For comparison purposes gaseous absorption is not included and the ground is non-reflecting.

Figure 1 shows numerical results calculated using the modified two stream radiation code. The ratio of effective fractional cloud cover to geometric fractional cloud cover (N_e/N) is shown as a function of geometric fractional cloud cover (N) for the simulated broken cloud fields (for plane parallel clouds $N_e/N = 1$). Computations are carried out for a solar zenith angle of 60^o for clouds with aspect ratios of 2, 1 and 0.5 . N_e/N is found to be greater than unity because a large amount of the direct solar radiation is intercepted by the cloud sides. As might be expected high aspect ratio clouds have the highest ratio of N_e/N. Figure 1 can be compared with figure 2 which shows results from a Monte Carlo model (reproduced from figure 5a of Kite 1987) and shows good quantitative as well as qualitative agreement. Numerical results from the Monte Carlo model are in much better agreement with the modified two stream code than with the standard two stream code. However the modified two stream code over-estimates the ratio N_e/N by typically 20%. This is because the modified two stream code does not allow diffuse radiation to pass through the cloud sides. For a solar zenith angle of 0^o Kite (1987) finds that the ratio N_e/N is less than unity, whereas our modified two stream code predicts $N_e/N = 1$. Again this is because the modified two stream code does not allow diffuse radiation to pass through the cloud sides.

4 Conclusion

This note has shown how the interception of direct solar radiation by the cloud sides can be included in a two-stream radiation code. Previous works, using Monte Carlo models, show that this is an important effect that can significantly enhance the cloud albedo. However, the method described here is no more computationally expensive than a standard two-stream radiation code and is much cheaper than Monte Carlo models.

Aircraft measurements described by Kite (1987) indicate that the effective fractional cloud cover (N_e) is a non-linear function of the geometric fractional cloud cover (N) and that an approximate relationship between them is given by $N_e = N^2$, which is very different from the results shown by both figures 1 and 2. As in Kite (1987), only the effect of cloud geometry has been examined by this note and cloud inhomogeneities have been ignored. Previous works show that both the cloud geometry and cloud inhomogeneities are important in determining the cloud-radiation interaction. Most works have concentrated on either the cloud geometry or the cloud inhomogeneities but have not studied both simultaneously and have thus failed to adequately explain observational results. It will be necessary to use more realistic simulations of broken cloud fields to understand the observational results. However, this is beyond the scope of this note and is left for future work.

5 References

F.M. Breon. 1992. Reflectance of broken cloud fields: simulation and parameterization. *J. Atmos. Sci.*, **49**, 1221-1232.

J.A. Coakley. 1991. Reflectivities of uniform and broken layered clouds. *Tellus*, **43B**, 420-433.

J.M. Edwards and A. Slingo. 1994. A comprehensive two-stream radiation code. Sensitivity studies in a GCM. AMS, eight conference on atmospheric radiation, January 1994, Nashville, Tennessee, 116-117.

P.R. Jonas. 1994. On the reflectance of cellular cloud layers. *Q.J.R. Meteorol. Soc.*, **120**, 221-229.

A. Kite. 1987. The albedo of broken clouds. *Q.J.R. Meteorol. Soc.*, **113**, 517-531.

T. Kobayashi. 1988. Parameterization of reflectivity for broken cloud fields. *J. At-*

CURRENT JCMM INTERNAL REPORTS

This series of JCMM Internal Reports, initiated in 1993, contains unpublished reports and also versions of articles submitted for publication. The complete set of Internal Reports is available from the National Meteorology Library on loan, if required.

1. **Research Strategy and Programme.**
   K A Browning et al
   January 1993

2. **The GEWEX Cloud System Study (GCSS).**
   GEWEX Cloud System Science Team
   January 1993

3. **Evolution of a mesoscale upper tropospheric vorticity maximum and comma cloud from a cloud-free two-dimensional potential vorticity anomaly.**
   K A Browning
   January 1993

4. **The Global Energy and Water Cycle**
   K A Browning
   July 1993

5. **Structure of a midlatitude cyclone before occlusion.**
   K A Browning and N Roberts
   July 1993

6. **Developments in Systems and Tools for Weather Forecasting.**
   K A Browning and G Szejwach
   July 1993

7. **Diagnostic study of a narrow cold frontal rainband and severe winds associated with a stratospheric intrusion.**
   K A Browning and R Reynolds
   August 1993

8. **Survey of perceived priority issues in the parametrizations of cloud-related processes in GCMs.**
   K A Browning
   September 1993

9. **The Effect of Rain on Longwave Radiation.**
   I Dharssi
   September 1993

10. **Cloud Microphysical Processes - A Description of the Parametrization used in the Large Eddy Model.**
H Swann
July 1994

11. **An Appreciation of the Meteorological Research of Ernst Kleinschmidt.**
A J Thorpe
May 1992

12. **Potential Vorticity of Flow Along the Alps.**
A J Thorpe, H Volkert and Dietrich Heimann
August 1992

13. **The Representation of Fronts.**
A J Thorpe
January 1993

14. **A Parametrization Scheme for Symmetric Instability: Tests for an Idealised Flow.**
C S Chan and A J Thorpe
February 1993

15. **The Fronts 92 Experiment: a Quicklook Atlas.**
Edited by T D Hewson
November 1993

16. **Frontal wave stability during moist deformation frontogenesis. Part 1. Linear wave dynamics**
C H Bishop and A J Thorpe
May 1993

17. **Frontal wave stability during moist deformation frontogenesis. Part 2. The suppression of non-linear wave development.**
C H Bishop and A J Thorpe
May 1993

18. **Gravity waves in sheared ducts.**
S Monserrat and A J Thorpe
October 1993

19. **Potential Vorticity and the Electrostatics Analogy: Quasi-Geostrophic Theory.**
C Bishop and A J Thorpe
November 1993

20. **Recent Advances in the Measurement of Precipitation by Radar.**
A J Illingworth
April 1993

21. **Micro-Physique et Givrage. Cloud Microphysics and Aircraft Icing.**
A J Illingworth
May 1993

22. **Differential Phase Measurements of Precipitation.**
M Blackman and A J Illingworth
May 1993

23. **Estimation of Effective Radius of Cloud Particles from the Radar Reflectivity.**
N I Fox and A J Illingworth
May 1993

24. **A Simple Method of Dopplerising a Pulsed Magnetron Radar.**
L Hua, A J Illingworth and J Eastment
November 1993

25. **Radiation and Polar Lows.**
George C Craig
February 1994

26. **Collected preprints submitted to International Symposium on the Life Cycles of Extratropical Cyclones; Bergen, Norway, 27 June - 1 July 1994**
April 1994

27. **Convective Frontogenesis**
Douglas J Parker and Alan J Thorpe
April 1994

28. **Improved Measurement Of The Ice Water Content In Cirrus Using A Total Water Evaporator**
Philip R A Brown and Peter N Francis
April 1994

29. **Mesoscale Effects of a Dry Intrusion within a Vigorous Cyclone**
K A Browning and B W Golding
April 1994

30. **GEWEX Cloud System Study, Science Plan**
May 1994

31. **Parametrization of Momentum Transport by Convectively Generated Gravity Waves**
R Kershaw
February 1995

32. **Mesoscale Modelling Newsletter, No. 5**
May 1994

33. **Observations of the mesoscale sub-structure in the cold air of a developing frontal cyclone**
K A Browning, S A Clough, C S A Davitt, N M Roberts and T D Hewson
May 1994

34. **Longwave Radiative Forcing of a Simulated Tropical Squall Line**
Imtiaz Dharssi
July 1994

35. **On the nature of the convective circulations at a kata-cold front**
K A Browning
September 1994

36. **Collected preprints of papers submitted to the COST-75 International Seminar on Advanced Weather Radar Systems, Brussels, 20-23 September 1994**
November 1994

37. **Use of satellite imagery to diagnose events leading to frontal thunderstorms: Parts I and II of a case study**
K A Browning and N M Roberts
November 1994

38. **The role of spaceborne millimetre-wave radar in the global monitoring of ice cloud**
P R A Brown, A J Illingworth, A J Heymsfield, G M McFarquhar, K A Browning and M Gosset
December 1994

39. **Potential Vorticity Inversion**
Michal Ziemianski
October 1994

40. **Theory of mature tropical cyclones; A comparison between Kleinschmidt (1951) and Emanual (1986)**
Suzanne L Gray
December 1994

41. **Dispersion and removal of pollutants during the passage of an atmospheric frontal system**
N R Gimson
December 1994

42. **The role of snow sublimation in frontogenesis**
D J Parker and A J Thorpe
December 1994

43. **Potential vorticity and the electrostatics Analogy: Ertel-Rossby formulation**
A J Thorpe and C H Bishop
December 1994

44. **Mesoscale aspects of extratropical cyclones: an observational perspective**
K A Browning
January 1995

45. **A Polar Low Outbreak: Evolution and Mesoscale Structures**
T D Hewson, G C Craig and C Claud
February 1995

46. **Generation of near-surface gusts by deep convection**
K Nakamura and R Kershaw
April 1995

47. **Attribution concepts applied to the omega equation**
S A Clough, C S A Davitt and A J Thorpe
June 1995

48 **Parametrization of mixed-phase cloud and precipitation**
Susan P Ballard and M Gerard Hutchinson
June 1995

49 **Short-range forecasting of stratocumulus: Initialization V Prediction**
Susan P Ballard, Simon D Jackson and B Macpherson
June 1995

50 **Contributions of the JCMM/Dept of Meteorology Radar Group to the 27th AMS Radar Meteorology Conference, Vail October 1995**
June 1995

51 **Cold pools in shear**
Douglas J Parker
September 1995

52 **High-resolution analysis of frontal fracture**
K A Browning, S P Ballard and C S A Davitt
September 1995

53 **The Albedo of Broken Cloud Fields: Calculations using a modified two stream radiation code**
Imtiaz Dharssi and Roy Kershaw
October 1995

Met Office Joint Centre for Mesoscale Meteorology Department of Meteorology
University of Reading PO Box 243 Reading RG6 6BB United Kingdom
Tel: +44 (0)118 931 8425 Fax: +44 (0)118 931 8791
www.metoffice.com